Proceedings of the Fourth International Coral Reef Symposium, Manila, 1981, Vol. 1

A COMPARATIVE ANALYSIS OF CORAL DAMAGE ON RECREATIONALLY USED REEFS WITHIN BISCAYNE NATIONAL PARK, FLORIDA

James T. Tilmant and George P. Schmahl
National Park Service, South Florida Research Center
P.O. Box 279, Homestead, Florida 33030 U.S.A.

ABSTRACT

A three-year study of coral patch reefs documented the incidence of physical damage to corals in relation to human use. Four bouyed patch reefs were compared to a similar set of four unmarked reefs.

Eight repetitive 30 min systematic swims, conducted seasonally at each study reef, revealed mean incidences of damage ranging from 35 to 140 corals/count. Significant differences were not observed on less used unmarked reefs in most cases. Octocorallia comprised over 85% of the total damage observed. This coincided with the approximate proportion of that groups' occurrence in the coral community. Scleractinia averaged less than 5% of the total damage which was consistently less than their proportional occurrence. Annual visitation ranged from 3400 to 3600 persons on the bouyed reefs studied. The most frequent recreational activities observed were snorkeling and spearfishing.

Natural wave action and substrate erosion were believed to account for the vast majority of coral damage encountered. Natural damage masked specific incidence of damage by swimmers or boaters. General boat operation in the area studied was found to be seriously affecting individual large colonies due to groundings.

INTRODUCTION

Concern for coral reef preservation has produced a number of studies describing man's impact on reef ecosystems (Johannes 1975 and Endean 1976). While such studies have greatly increased our knowledge of coral reefs and illustrated preservation need, there still remains much information required for management. Unresolved fundamental questions include: What activities at what levels can be permitted without significant alteration to the community; what size area will insure maintenance of species numbers and genetic variability; and what techniques can provide the best means of monitoring these resources to detect impacts.

Managers of marine preserves are particularly concerned with efficient methods to evaluate their resources (Dahl 1977). Emphasis has been placed on development of rapid visual techniques to allow monitoring (Kenchington 1978, Jones and Thompson 1978, Done 1980). In this paper, we report on an underwater visual census technique developed to evaluate the incidence of physical damage to corals on recreationally used reefs. We then present an analysis of observations made during a three-year monitoring period from 1978-1980. These investigations form a portion of a larger on-going study designed to evaluate over-all human impacts to the coral reef ecosystem at Biscayne N.P. (Tilmant et al. 1980).

STUDY AREA

Biscayne N.P. is located in the southern part of Dade County Florida (Fig. 1). The park includes the waters of Southern Biscayne Bay, Northern Card Sound, the northernmost islands of the Florida Keys, and offshore waters and coral reefs out to the 10 fathom depth contour. Reefs within the park

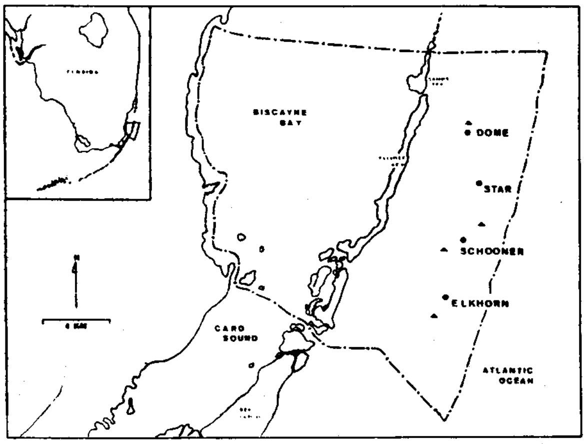

Figure 1. Biscayne National Park Dade County, Florida. Broken line represents the park boundary. Locations of experimental (buoyed) reefs are indicated as black circles. Black triangles represent location of control reefs.

represent the approximate northern limit of an extensive coral reef system extending from Miami 360 km southwest, terminating at the Dry Tortugas in the southeastern Gulf of Mexico.

Within Biscayne National Park, a discontinuous elongated barrier reef is located approximately 7 km offshore of the keys. Between these outer reefs and the island chain lies a large lagoonal area in which thousands of patch reef occur (Marszalek et al. 1977). Morphological characteristics of patch reefs have been described by Jones (1977).

The park is located 24 km south of Miami, Florida (1.5 million population) and is therefore readily accessible to a large number of recreational boaters. Annual park visitation is approximately 200-250 thousand persons of which about 10 thousand persons swim or dive on the coral reefs. Most of the visitation occur on weekends.

METHODS

Eight coral reefs visually determined to be representative of typical lagoonal patch reefs found within the park, were selected for study (Fig. 1). Four of these reefs were marked with mooring buoys and were described in a park visitor brochure. These four reefs received heavier use and were considered "experimental." The remaining four reefs were selected on the basis of their similarity in topographic relief and community structure to each of the buoyed reefs and were left unmarked as controls. Significant differences in damage between experimental and control reef pairs were assumed to reflect impact from recreational use.

Boat patrols to monitor study reef use were conducted from early morning until late afternoon on weekends when maximum-park use occurs. During such patrols, all boat use of buoyed and control reefs was noted. The proportion of park visitors using the buoyed reefs was then determined from estimated total boat use of the park on the day patrolled.

The occurrence of physically damaged corals was assessed using a repetitive series of timed 30 min systematic swims with SCUBA over each study reef. Performance curves derived from repetitive test surveys revealed that a mean value from eight 30 min counts provided a representative index of damage for a given reef survey. Surveys were repeated following winter and summer periods each year. As a coral reef substrate is largely coral skeletons, rigid criterion were established by which corals were considered to be recently damaged and counted (Table 1). All damaged Octocorallia, Scleractinia and Milleporina specimens meeting the criterion were recorded on underwater writing tablets. For Scleractinian corals, the species, size, and exact nature of damage was noted. On all but two patch reefs, the 30 min observation period allowed systematic coverage of the entire reef. On the two largest reefs, observations were proportioned to include each major reef zone.

Table 1. Criteria by which physically damaged corals were evaluated prior to inclusion in survey counts.

DAMAGED INCLUDED IN COUNT	DAMAGE NOT INCLUDED IN COUNT
1. Colony overturned or loose from base -no encrusting overgrowth or apparent new growth on basal surface. Note: *Agaricia* sp. and *Porites* sp. commonly occur loose naturally. Counted as damage only if pieces were broken or bleached due to being overturned.	1. Specimen loose with substantial tissue deterioration and/or significant encrusting overgrowth (macrophytic algae, hydroid, sponge, bryozoan or *Millepora*).
2. Rock or coral head overturned with attached colonies underneath.	2. Fallen specimen with upright new growth.
3. Specimen broken along stem or branch (counted as one per colony) — no macrophytic algal overgrowth at break point.	3. Broken branches with substantial tissue degeneration and/or encrusting overgrowth (as in item 1).
4. Loose branches with clean breaks (Scleractinia and *Millepora*) — not counted if associated with item 1.	4. Cuts, scars, or abrasions with encrusting overgrowth or new growth.
5. Cuts, scars, abrasions with no encrusting overgrowth or apparent new growth.	5. Biological damage: a. Predation (*Hermodice*, corallivore fish marks, inter-specific or inter-phyletic aggression). b. Algal infection.
6. Qualifiers for Scleractinia: size of coral colony exact type of damage (overturned, loose, scarred, etc.) and enumeration of number and extent of cuts, scars or broken branches.	6. Zooxanthellae expulsion (bleaching) with no apparent physical cause.

Data was analyzed for differences between experimental and control reefs and for individual reefs over time using analysis of variance (ANOVA), proportional damage among coral types by chi square, and correlation to recreational use and wind conditions with Model II single factor regression and multiple regression analysis.

Concurrent studies of coral abundance and diversity (Jaap and Wheaton 1978) provided information on coral community structure which were compared with damage levels observed. Wind data was obtained from the Florida Power and Light Company which operates a generating plant on the shore of southern Biscayne Bay and the U.S. Air Force Flight Operations Center at the Homestead Air Force Base located 5 km west of the park.

RESULTS

Systematic visual underwater surveys resulted in a satisfactory index of physically damaged corals on the reefs studied. Significant differences between individual observer counts (ANOVA), due to subjective differences between observers, occurred in only 13 of 64 surveys ($p<.05$). Count variability resulted in 95% confidence intervals ranging from 4 to 35% of the mean number damaged corals/30 min count and averaged within 13%. Variability in observer counts lessen the accuracy by which statistical differences between surveys can be detected, but in our study when marked differences occurred between reefs, they usually greatly exceeded observer variability.

Results of our observations during a three year period are shown in Figs. 2a-d. Mean frequency of damaged coral encounters ranged from 35/30 min count to 140/30 min count. Marked seasonal differences of damaged corals were noted on all reefs. Although the magnitude of seasonal changes varied greatly, a highly consistent pattern of increased damage following the winter period and decreased damage during the later summer counts was observ-

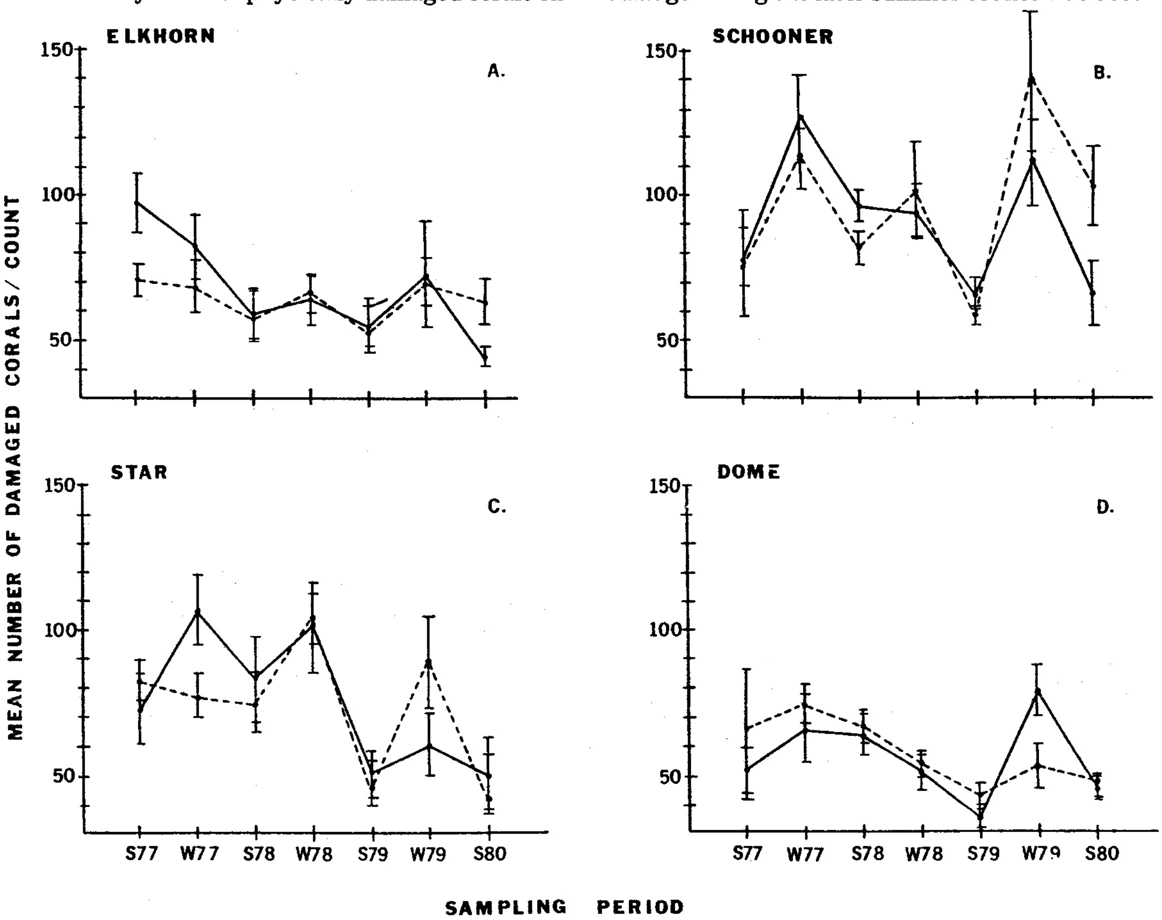

Figure 2. Mean number of damaged corals observed per 30 min swim for buoyed-control reef pairs. Fall 1977-Fall 1980. Solid line represents buoyed reefs. Broken lines represent unmarked control reefs.

ed (Table 2). The only exceptions to this pattern occurred on the Elkhorn reefs (buoyed and control reefs) during the first winter, and on Dome reefs and the buoyed Schooner reef during the 78-79 winter.

We feel seasonal increases in damage can best be accounted for by increased winds and rough seas that occur during the winter seasons (Table 2). The lower maximum winds that occurred during the 1978-79 winter may have accounted for the lack of increased damage observed on Dome, Dome Control and Schooner reefs. Boater and diver use of the park is highest during summer months when incidence of damaged corals generally declined (Table 2).

Comparison of buoyed and control reef pairs, showed that, although significant differences did occur at some sample points, each reef pair followed highly similar patterns in overall damage. Significant differences between buoyed and control reefs did not follow a consistent pattern that could be readily attributed to human use (Figs. 2a-d). In six cases, significantly higher damage was observed on the buoyed reefs and in six other cases significantly higher damage was on the less used control reefs. In all cases where significant differences were noted, subsequent observations revealed no consistent differential pattern in damage level between buoyed and control reefs.

Approximately 79 percent of reef use observed occurred on buoyed reefs. Each buoyed reef received three or more times as much use as its control. The two largest reefs, Elkhorn and the Elkhorn Control reef received the heaviest amount of use. Our observations indicate approximately 1.5 percent of the boaters using the park visit the buoyed experimental reefs. This represents an annual use of from 850-900 boats (3400-3600 persons) on the reefs studied. The most frequent recreational activities have been snorkeling and spearfishing.

Although significant coral damage from recreational use was not evident through buoyed and control reef comparisons, the possibility of a relationship between level of damage and use was further tested by regression analysis. All surveys were pooled and recorded damage levels regressed on the observed level of recreational use for each reef during the period preceding the survey. Results using raw score mean damage levels showed no linear or curvelinear relationship. However since coral density among the reefs differed, analyses were also conducted with damage levels weighted to coral density. Coral data collected by Jaap and Wheaton (1978) were used for this purpose. When reef damage levels were adjusted by density factors and regressed on recreational boat use, a significant linear correlation resulted ($r = 0.62$, $p < .001$).

The above correlation of observed damage to reef use ignores potential wind and exposure effects, although these are obviously important factors for

Table 2. Pattern of seasonal change in number of physically damaged corals encountered per 30 min systematic swim. + indicated increase, — indicated a decrease from prior damage frequency. Also shown are corresponding wind conditions and reef use during each period.

Reef	PERIOD					
	Winter 77	Summer 78	Winter 78	Summer 79	Winter 79	Summer 80
Elkhorn	—*	—*	+	—	+	—*
Elkhorn Control	—	—	+	—*	+*	—
Schooner	+*	—*	—	—*	+*	—*
Schooner Control	+*	—*	+*	—*	+*	—*
Star	+*	—*	+	—*	+	—
Star Control	+	—	+*	—*	+*	—*
Dome	+	—	—*	—*	+*	—
Dome Control	+	—	—*	—*	+*	—
Wind Conditions (m/sec)						
Avg. Monthly Max.	18.3	14.2	15.6	14.7	17.1	18.0
Avg. daily Max.	8.9	8.4	10.2	9.5	9.9	9.4
No. Boats using Park						
Reefs	3,164	6,723	2,988	5,340	2,855	5,716

*Change indicated was statistically significant at $p < .05$.

consideration. Since winds are generally higher when reef use is low, the slope of the regression line obtained ($y=105.1+0.4x$) would be expected to be somewhat steeper if wind bias were removed. When coral density adjusted damage levels were correlated to both preceding wind conditions (mean monthly maximum) and recreational use, only a slightly improved regression coefficient was obtained ($r = 0.63$; $p < .001$). However, sea conditions indicated by monthly maximum wind is not considered highly dependable and more direct observations of sea states would probably have greatly increased this correlation.

Distribution of damage among organism groups was found to be consistent on all reefs studied. Damage to sea whips and plumes comprised over 75% of the total damage recorded. Sea fans comprised approximately 10%. The proportion of total damage comprised by all soft corals (Octocorallia) did not differ significantly from their proportional occurrence in the community ($p > 0.50$). Scleractinian damage (less than 5%) was significantly less than their proportional occurrence indicating a higher resistance to damage ($p < .001$). *Millepora* appears highly susceptible to damage as it comprised a significantly higher proportion of the damage observed than its abundance in the community ($p < .001$). The relatively higher levels of coral damage observed on the Schooner and Star reef complexes were accounted for, in part, by their higher abundance of soft corals.

Although damage to corals during recreational use of reefs at Biscayne NP does not appear to be significantly altering the coral community on the whole, specific damage to the larger coral colonies from boat groundings is of concern. During this study, at least six boat groundings have occurred among the eight reefs studied. Each of these groundings have resulted in damage to one or more of the largest colonies present. Largest colonies reach to within a meter of the surface and are highly vulnerable. A high incidence of damage to these colonies may eventually result in loss of many such older corals. Reef fish and other organisms dependent on the cavernose habitat provided by such large corals would in turn be affected.

CONCLUSIONS

The number of corals on the smallest of the patch reefs studied is estimated to have approached 85,000 colonies. During a typical 30-min swim covering the entire reef, not more than 200 damaged corals were ever encountered. The rarity of damaged coral in relation to the censused population therefore precludes practical use of traditional quadrat or line transect sampling techniques to quantify damage levels. The time based systematic swim method described has provided statistically valid and repeatable observations of the number of physically damaged corals on a given reef or reef area. The method is simple and requires little precensus preparation. Thus, rapid comparative evaluations among reef areas can be made.

Monitoring of coral reefs at Biscayne N.P. has revealed that a significant amount of physical damage occurs naturally to coral organisms during the winter season annually. Imposed on natural low damage levels during summer months are increased levels of damage due to human use. At the present level of reef use (i.e. up to 1500 persons/reef annually), additional human impacts do not appear cumulative or extensive enough to mask natural damage. However, a significant linear correlation of reef use and incidence of physical damage was evident and predictions of the incidence of coral damage at higher use levels can be made.

The problem of frequent boat groundings on reefs is a serious one at Biscayne N.P. and on other Florida reefs (Hudson 1981). This problem is largely related to the high density of small shallow patch reefs within the lagoonal area and the inexperience of many recreational boaters. Public education programs may be the best approach in reducing such impacts.

ACKNOWLEDGEMENTS

This research was supported by the National Park Service, South Florida Research Center in Everglades National Park, Homestead, Florida. Principal persons assisting in the collection of data were Doug Morrison, Richard Conant, Jr., and Scott Andree. We also wish to acknowledge the support and assistance of the Biscayne National Park staff. We are indebted to Drs. Gary Hendrix, James Porter, and James Kushlan for critical review of the manuscript.

REFERENCES

Dahl, A.L. 1977. Monitoring man's impact on Pacific Island reefs. Proc. 3rd Int. Coral Reef Symp. 2: 571-576.

Done, T.J. 1980. Reconnaissance of reef benthos as an aid to management. Memo. Rpt. to the G.B.R.M.P.A. Part I: 1-38.

Endean, R. 1976. Destruction and recovery of coral reef communities. In O.A. Jones and R. Endean (eds.). Biol. and Geol. of Coral Reefs. Vol. 3. Pp 215-254. London: Academic Press.

Hudson, J.H. 1981. Growth rates in *Montastrea annularis:* a record of environmental change in Key Largo Coral Reef Marine Sanctuary, Florida. Bull. Mar. Sci. 31(2): 444-459.

Jaap, W.C. and J. Wheaton. 1978. Unpub. report to NPS on coral reef research in Biscayne N.M. 145 p. Memo.

Johannes, R.E. 1975. Pollution and degradation of coral reef communities. *In* E.J. Ferguson-wood and R.E. Johannes (eds.). Tropical Marine Pollution. Pp. 13-51. Elsevier Oceanography Series No. 12. N.Y.: Elsevier Sc. Pub.

Jones, J.A. 1977. Morphology and development of southeastern Florida patch reefs. Proc. 3rd Int. Coral Reef Symp. 2: 231-235.

Jones, R.S. and M.J. Thompson. 1978. Comparison of Florida reef fish assemblages using a rapid visual technique. Bull. Mar. Sci. 28(1): 159-172.

Kenchington, R.A. 1978. Visual surveys of large area of coral reefs. *In* D.R. Stoddart and R.E. Johannes (eds.). Coral Reefs: Research Methods. Pp. 149-161. Unesco Monog. on Oceanographic Methodology. No. 5, Paris: Unesco.

Marszalek, D.S., G. Babashoff, Jr., M.R. Noel and D.R. Worley. 1977. Reef distribution in south Florida. Proc. 3rd Int. Coral Reef Symp. 2: 223-229.

Tilmant, J.T., G.P. Schmahl and D. Morrison. 1980. An ecological assessment of Biscayne National Monument's coral reefs in relation to recreational use. *In* J. Gouge (ed.). Proc. 2nd Conf. on Sci. Resch. in the Nat. Pks. San Francisco, Ca. 9: 183-224.